



## Carbon Capture - Affordability, Challenges, and Impact

### INTRODUCTION

Carbon capture technologies, commonly referred to as Carbon Capture and Storage (CCS) or Carbon Capture, Utilization and Storage (CCUS), are designed to reduce greenhouse gas emissions by capturing carbon dioxide from industrial sources or directly from the atmosphere and preventing it from entering the climate system. These technologies are often presented as a key solution for mitigating emissions from hard-to-abate sectors such as cement, steel, and fossil fuel based power generation. However, despite growing interest and policy support, the feasibility of mass adoption across countries remains uncertain due to significant economic, manufacturing, infrastructural and human capital constraints.

#### Affordability+ Economic Feasibility

The affordability of carbon capture technology is currently one of the greatest barriers to widespread adoption. Carbon capture systems are highly capital intensive, with large industrial projects frequently requiring investments of hundreds of millions to over a billion dollars. In addition to initial construction costs, operators must bear long term operational expenses associated with energy use, maintenance, and monitoring. Capture costs vary widely depending on the source of emissions and technology used, but they often exceed the prevailing price of carbon in most markets. Direct air capture, while attractive due to its flexibility in location, is particularly expensive, with costs far exceeding those of point source capture.

As a result, carbon capture is generally not economically viable without strong government intervention. Subsidies, tax, credits, and public funding can improve feasibility, but these mechanisms are unevenly distributed across countries. Wealthier nations with established carbon markets and fiscal capacity are better positioned to support carbon capture deployment, while developing economies face substantial financial constraints. Consequently, the technology remains inaccessible to many countries that are also among the most vulnerable to climate change impacts.

#### Manufacturing + Technical Challenges

Manufacturing carbon capture systems at scale presents further difficulties. Many capture technologies rely on specialised materials such as chemical solvents, sorbents, or membranes which require precise production processes and are prone to degradation over time. This increases replacement costs and limits the durability of capture systems. Furthermore, the global manufacturing base for carbon capture equipment is still relatively small, preventing economies of scale that could reduce costs through mass production.

Another critical issue is the energy penalty associated with carbon capture. Operating capture systems requires significant additional energy, which can reduce the efficiency of power plants or industrial facilities by a substantial margin. This not only raises operational costs but can also increase indirect emissions if the additional energy is sourced from fossil fuels. These technological inefficiencies undermine the net environmental benefits of carbon capture and complicate its integration into existing industrial systems.

#### Infrastructure + Resources

Effective carbon capture deployment depends heavily on supporting infrastructure, particularly for the transportation and storage of captured carbon dioxide. CO<sub>2</sub> is typically transported via pipelines to geological storage sites, such as deep saline aquifers or depleted oil and gas reservoirs. However, dedicated CO<sub>2</sub> pipeline networks are limited and geographically concentrated, primarily in North America. Many regions lack both transport infrastructure and verified storage sites, making deployment logical, challenging and costly. In addition, developing storage sites requires extensive geological surveying, regulatory approval, and long-term monitoring commitments. Public concerns regarding safety, leakage risks, and environmental impacts can delay or prevent storage projects. These infrastructure and resource limitations create a coordination problem: capture facilities are not built without storage options, while storage infrastructure is not developed without guaranteed capture volumes.



#### Need for Expertise and Institutional Capacity

The deployment and operation of carbon capture systems require a high level of technical expertise. Engineers specialising in chemical processes, mechanical systems, and subsurface geology are essential for designing and maintaining capture and storage facilities. Many countries, particularly developing ones, lack sufficient skilled personnel and training programs to support large-scale deployment. Institutional capacity is equally important. Governments must establish clear regulatory frameworks governing carbon storage liability, long-term monitoring, and environmental safeguards. Weak or uncertain regulation increases investor risk and discourages private sector participation. Without coordinated policy, technical knowledge, and public trust, carbon capture projects struggle to gain approval and long-term viability.



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### Environmental and Socioeconomic Impacts

When implemented effectively, carbon capture can significantly reduce emissions from industries with limited low-carbon alternatives. This makes it a potentially valuable tool in achieving net-zero targets. However, critics argue that overreliance on carbon capture risks delaying the transition to renewable energy and energy efficiency measures. If used to justify continued fossil fuel extraction without addressing upstream emissions, carbon capture may offer limited net climate benefits.

From an economic perspective, carbon capture can stimulate innovation and create specialised jobs, particularly in engineering and infrastructure development. Nonetheless, the high public cost of supporting these projects raises concerns about opportunity costs and equity, especially if public funds are disproportionately allocated to large industrial emitters rather than broader climate solutions.



### Conclusion

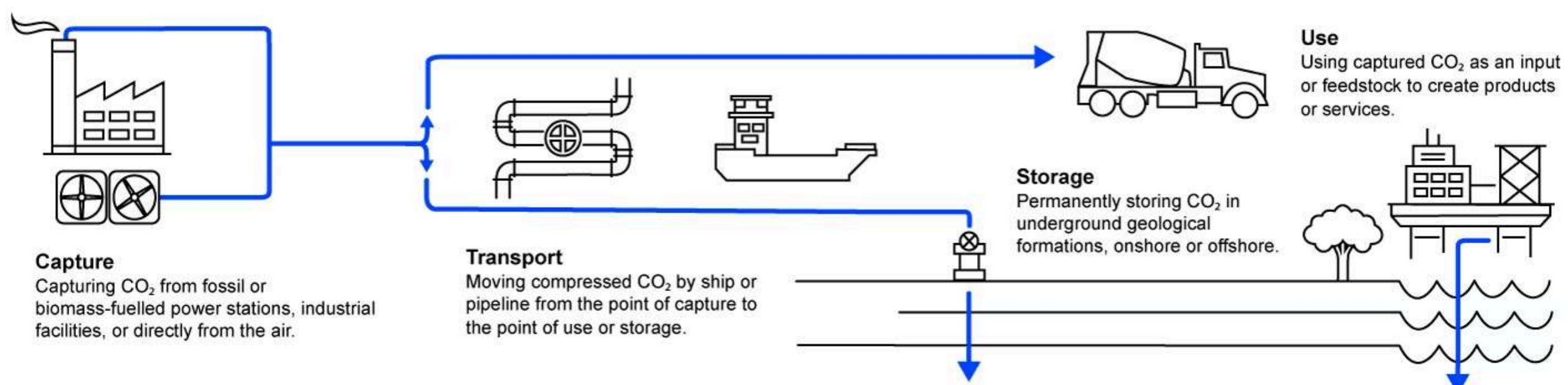
In conclusion, carbon capture technology is not currently affordable for mass adoption across countries without substantial and sustained policy support. High costs, manufacturing limitations, inadequate infrastructure, and shortages of technical expertise collectively constrain its global scalability. While carbon capture can play a meaningful role in reducing emissions from specific industrial sectors, it is best viewed as a complementary measure rather than a standalone solution. Achieving widespread adoption will require international cooperation, significant investment in infrastructure and skills, and policy frameworks that align economic incentives with long-term climate objectives.



## Carbon Capture - Market Size, Funding Trends, Collaboration, Competition, and Impact.

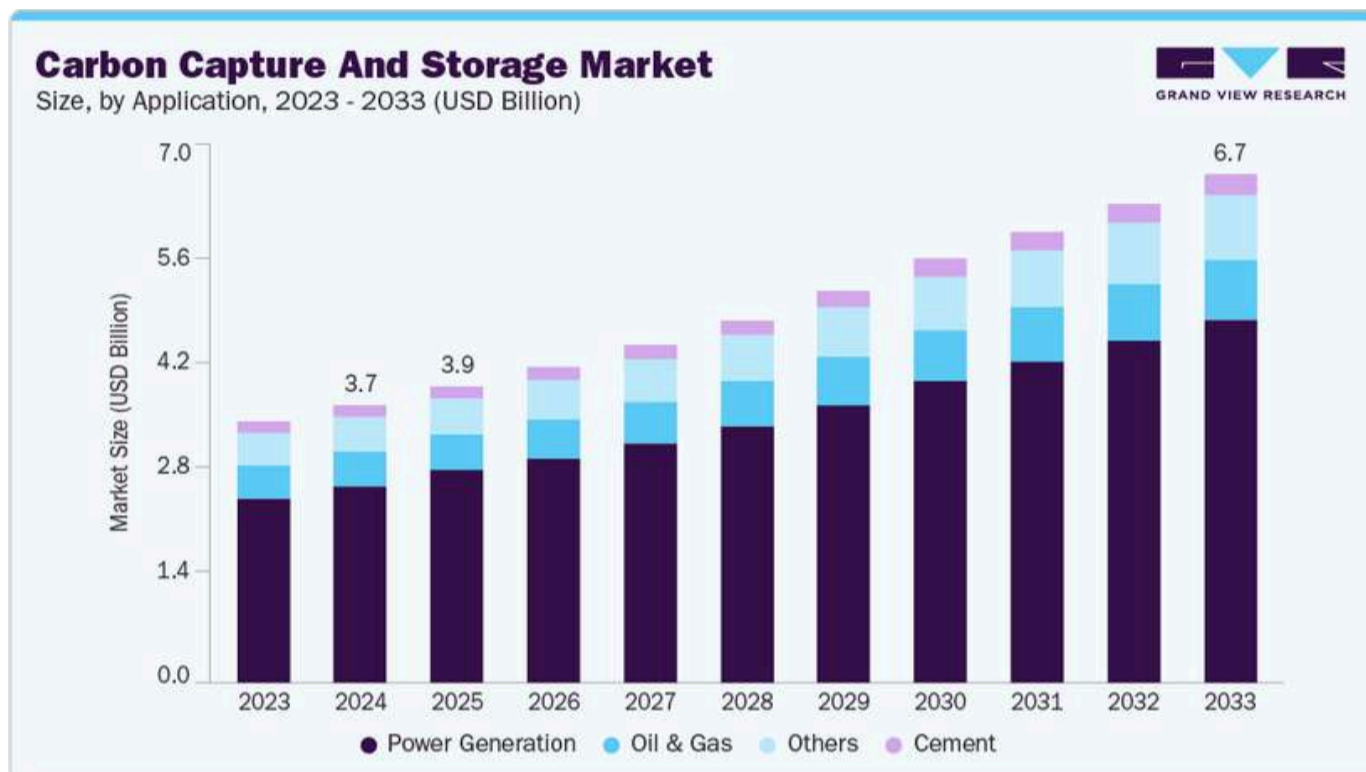
### Introduction

Carbon capture, utilization, and storage (CCUS) represents a pivotal technology in the global effort to mitigate climate change while sustaining economic growth. As of early 2026, the technology is at an inflection point, with operational capacity capturing over 50 million tonnes (Mt) of CO<sub>2</sub> annually, primarily from natural gas processing and industrial sources. This research goes deep into the market size, investment trends, interactions with established industries, and employment impacts, by using current data to understand this more clearly.



## Carbon Capture - Market Size, Funding Trends, Collaboration, Competition, and Impact.

### Market Size: Current State and Future Projections



The global CCUS market is valued USD 5.82 billion in 2025 that encompasses the services like Capture, Transportation, Utilization and Storage. This figure clearly reflects a maturing industry with around 45 commercial facilities worldwide, capturing CO<sub>2</sub> from power generation, fuel transformation, and industrial processes. Market segmentation highlights capture as the dominant service, accounting for the bulk of revenue due to its technical complexity and energy demands. By technology, solvents and sorbents lead, but chemical looping is emerging as the fastest-growing segment, offering efficiency gains in high-emission industries.

Projections indicate robust expansion, with the market reaching USD 17.75 billion by 2030 at a CAGR of 25%. This growth aligns with capacity forecasts: announced projects could enable 430 Mt of CO<sub>2</sub> capture annually by 2030, up from current levels, though this falls short of the 1 Gt needed for net-zero pathways under the IEA's Net Zero Emissions scenario. Regional dynamics are key—North America holds the largest share, bolstered by oil and gas integration via enhanced oil recovery (EOR), while Europe exhibits the highest CAGR (over 6%), driven by the EU Green Deal and targets for 50 Mt storage capacity by 2030. Asia-Pacific, including China, is diversifying, with over 100 demonstration projects contributing to 50 Mt capture by 2030 as predicted.

### Investments and Funding Trends

Investment in CCUS is accelerating, with cumulative global spending projected at \$80 billion by 2030, primarily in North America and Europe. This includes \$20 billion+ in government funding, such as US allocations under the Infrastructure Investment and Jobs Act (\$1.7 billion for demonstrations) and EU Innovation Fund grants. Private trends emphasize strategic partnerships—e.g., Fluor, Equinor, and Shell's agreements—and acquisitions, with over \$2.3 billion in direct air capture (DAC) investments from 2021–2025.

Venture capital in clean energy, including CCUS, rebounded to \$12.5 billion in 2024, up 8%. Trends include focus on DAC (2.47 Mt credits contracted 2022–2025) and blue hydrogen, with deal sizes dropping but volumes rising. Policy shifts, like US project cancellations, introduce uncertainty, potentially reducing \$7 billion in funding. Globally, cross-border collaborations (e.g., North Sea CO<sub>2</sub> transport) signal integrated funding models.

### Collaborations and Competitions with Established Industries



CCUS integrates with legacy sectors, often as a retrofit solution for hard-to-abate emissions. In oil and gas, it collaborates via EOR, extending field life and utilizing CO<sub>2</sub> from industrial sources—e.g., Chevron's investments in ION Clean Energy. Heavy industries like cement and steel benefit from mineralization, turning waste into products while capturing CO<sub>2</sub>, as seen in mining integrations. Partnerships abound: Baker Hughes-Frontier for CCS-data centers; Bloom Energy-Chart for fuel cells.

Competition emerges over resources—CCUS requires significant energy (up to 30% of plant output), potentially rivaling renewables for grid access. In power, it competes with direct electrification, though it's complementary for baseload stability. Economic analyses show older facilities may offer unexpected low-cost opportunities via proximity to storage, but oil price volatility could undermine viability. Overall, collaboration dominates, with ecosystems involving emitters (e.g., BP), capturers (e.g., ExxonMobil), and storers (e.g., Wolf Midstream).

### Employment Impacts

CCUS deployment promises substantial job creation, offsetting potential losses in fossil fuels. US projections indicate 200,000–300,000 direct job-years through 2030, with capture driving 90% via engineering, construction, and maintenance. Globally, the IEA implies similar scales from 430 Mt capacity by 2030, potentially creating 80,000–100,000 construction jobs and 30,000–40,000 operational roles by 2050.

State-level US data (e.g., Rhodium Group) shows retrofits and pipelines generating 71,000–174,000 annual jobs over five years for coal/gas plants. In Texas, 95 facilities could yield 18,000 project jobs and 9,000 ongoing ones. Broader effects include supply chain boosts, with every federal dollar leveraging four in economic activity. Challenges: Reskilling for displaced workers, as clean energy jobs grow faster than fossils as we saw from past years. Net positive, but equitable policies needed.

In summary, CCUS's economic trajectory hinges on policy stability and innovation, positioning it as a bridge to sustainability while fostering growth.

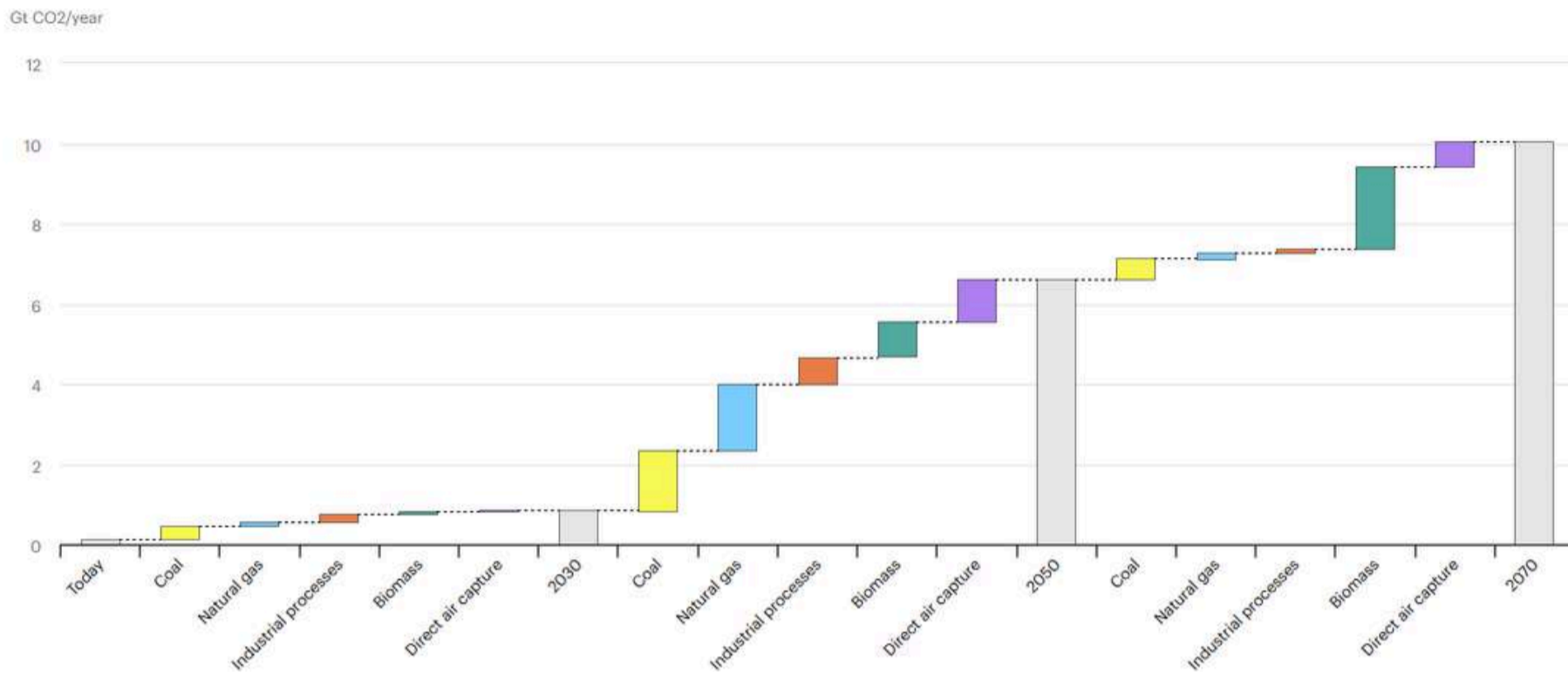
# Real-World Applications

Researcher: Jemima Editor: Lan Sun. Graphic Designer: Lan Sun



## Heavy Industry

Growth in world CO2 capture by source and period in the Sustainable Development Scenario, 2020-2070



Carbon capture specifically has many applications in the heavy industry, especially in sectors such as steel, cement and chemicals (Lebling). For cement, carbon could be captured during its release in chemical processing of raw materials. For steel, we could capture the emissions from blast furnaces and other manufacturing processes (Admin). For chemicals (and petrochemicals) we could capture carbon dioxide during the production of ammonia and ethanol. Finally, for power and waste, emissions from industrial power generation could be captured, including biomass-fueled plants. Carbon capture, utilization and storage (CCUS) can also be used to produce hydrogen from natural gas or coal to provide a low-carbon energy source. We could also apply this to bioenergy plants in the industry to balance hard-to-abate sectors.

In the heavy industry, there are also technological processes being used to make carbon capture efficient. For example, post-combustion capture is often used in this industry, which is when CO<sub>2</sub> is separated from gases after combustion in the air (Valentin). This is where CO<sub>2</sub> is removed from flue gases, often using a chemical solvent like amines. Pre-combustion is used in gasification to produce steel and chemicals. Oxy-fuel combustion is also used, which is where it's burned in oxygen instead of the air to produce a concentrated CO<sub>2</sub> stream for easier capture. This is commonly used in cement production.

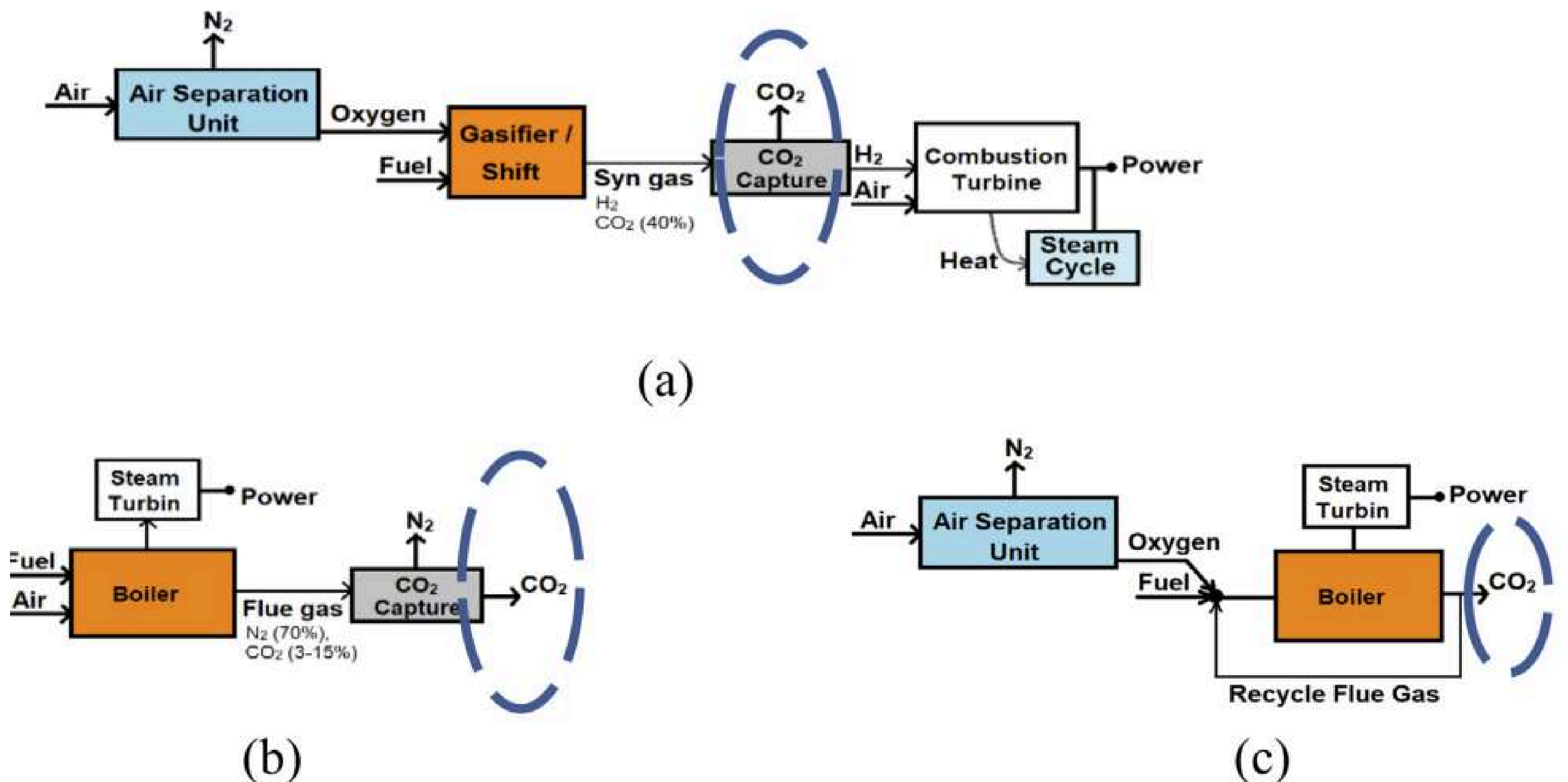


Fig. 1. (a) Pre-combustion, (b) post-combustion, and (c) oxy-combustion carbon capture schematics.

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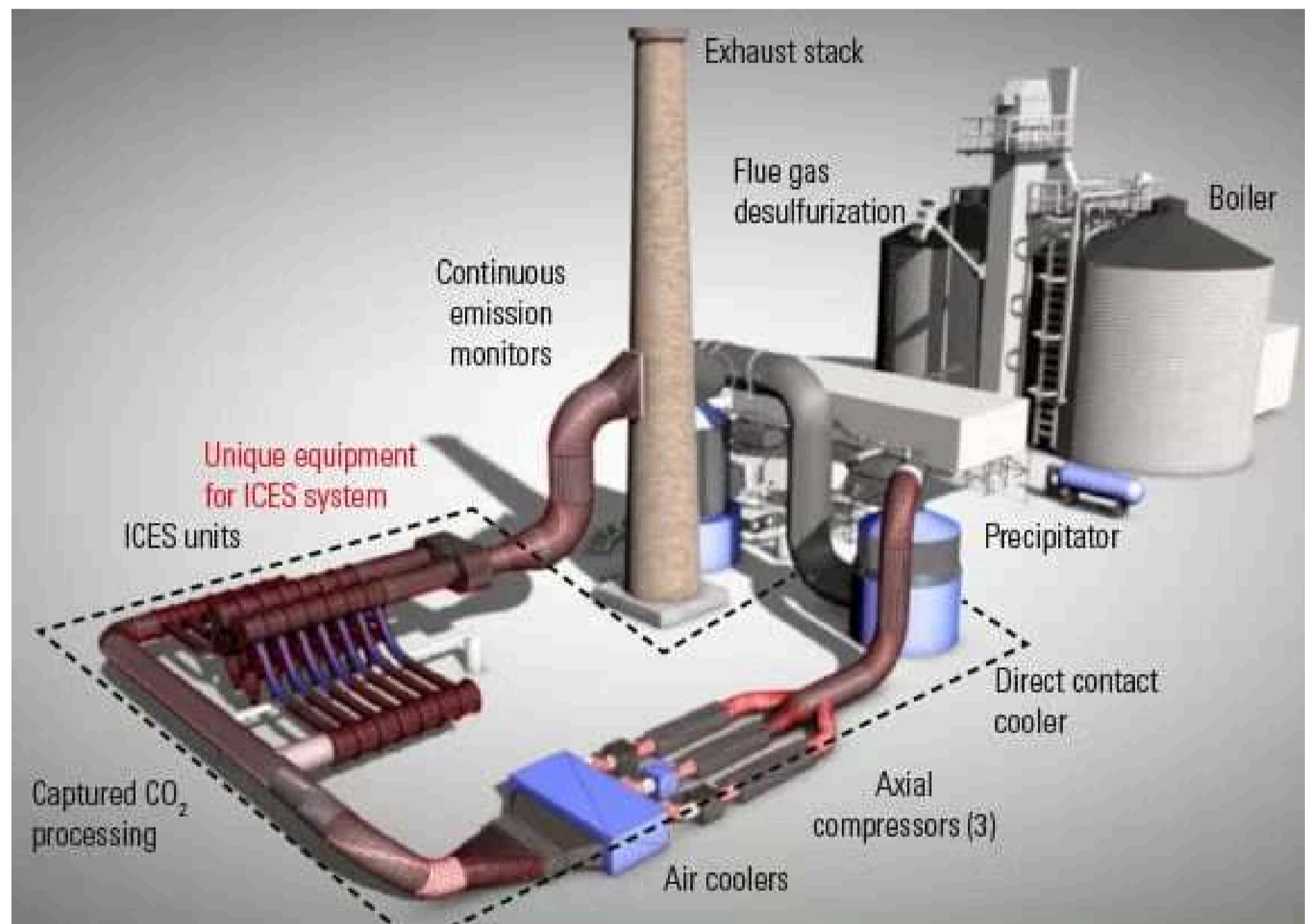


Carbon capture is also used in the power industry, and is important as it removes up to 95% of carbon emissions from coal and natural gas-plants. We could use CCS (carbon capture storage) to retrofit existing power plants, such as coal and gas fired power plants. This allows them to continue to generate electricity while reducing emissions, lowering costs in the power sector. Also, power plants equipped with CCUS can provide reliable, flexible power that supports grid stability, especially as wind and solar energy increase.

In a technological process - bioenergy with CCS (BECCS), biomass is used for energy and captures the resulting carbon dioxide. This creates negative emissions, which are ideal for meeting net-zero goals. CCS technology can also be applied on natural gas-fired, so growing electricity demands can be met from data centers and industrial expansion without high emissions.

Benefits of using carbon capture in the power sector are that it decarbonizes the existing infrastructure, has firm reliable power and supports net-zero goals. However, it is expensive to implement, it's technically and operationally complex and poses environmental and safety risks.

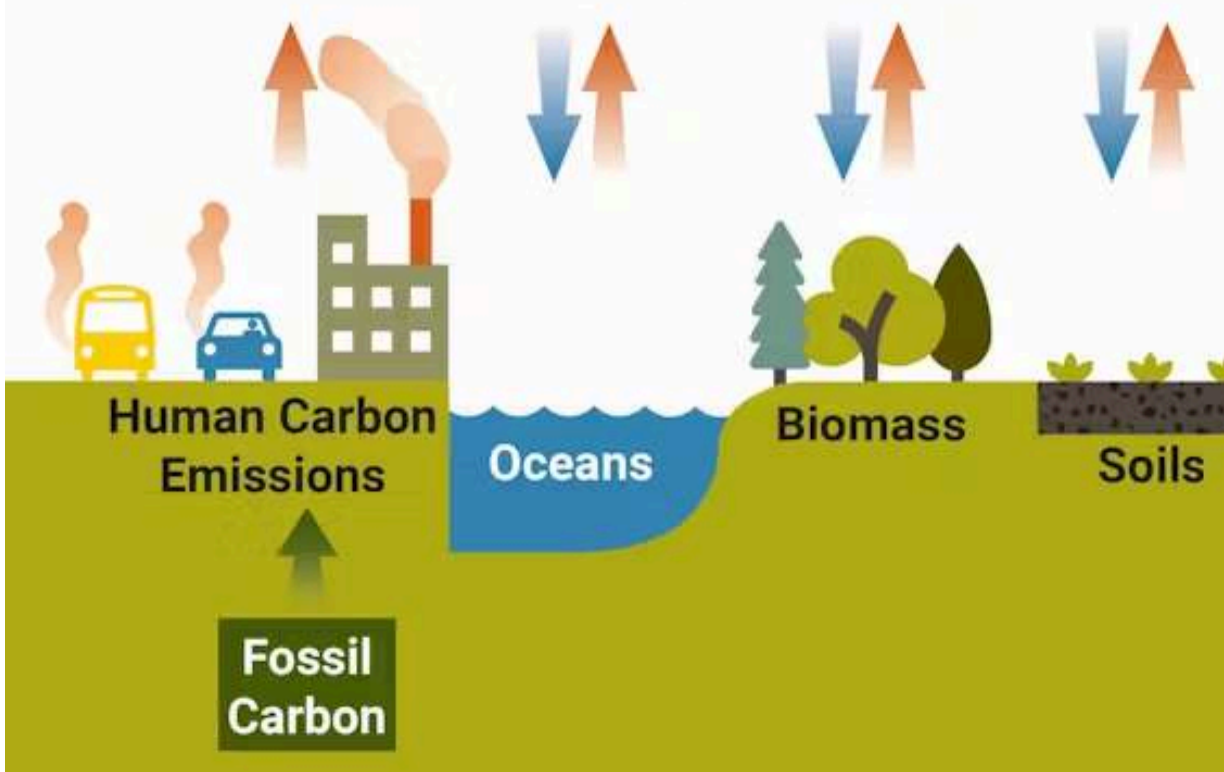
## Power Generation



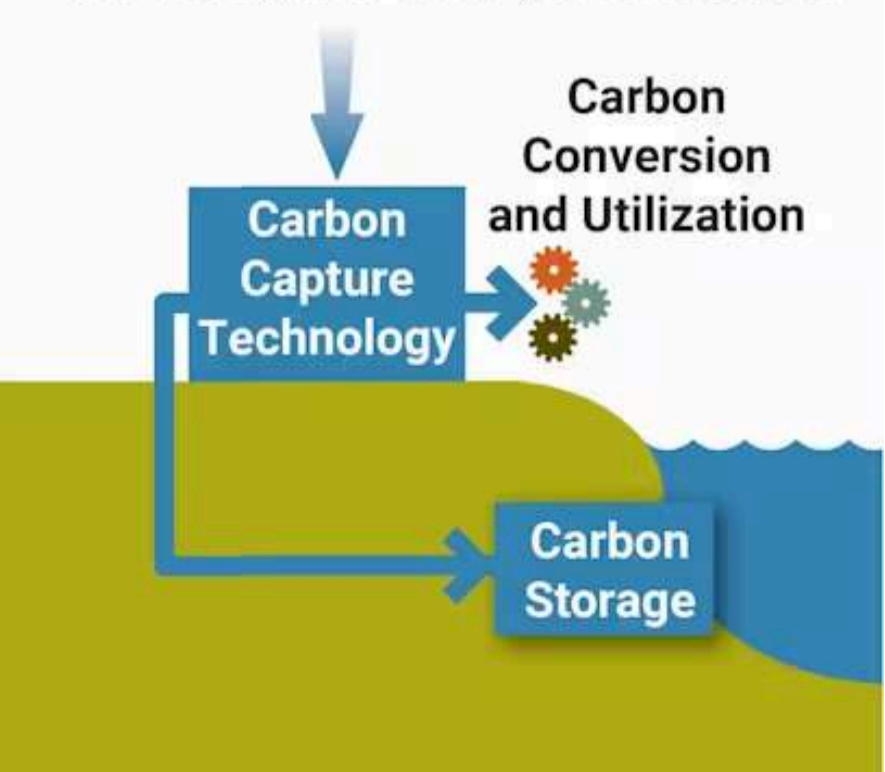
## Benefits of Carbon Capture

One of the foremost benefits of CCUS technologies is their potential to reduce CO2 emissions. Strategic deployment in high-emission sectors could contribute significantly towards global decarbonization goals, supplementing direct emission reductions from renewables and energy efficiency improvements.

**Natural processes** associated with oceans, biomass, and soils exchange carbon with the atmosphere at enormous scales.



**Carbon capture technology** takes carbon dioxide out of the atmosphere, the water, and from point sources.



CCUS enables continued operation of existing energy and industrial infrastructure while decarbonizing processes that are otherwise difficult to electrify directly, such as cement and steel production. By mitigating emissions without complete infrastructure replacement, CCUS can support energy security during the transition to cleaner energy systems.

The development of capture and utilization technologies stimulates innovation, economic activity, and specialized employment in engineering, materials science, and geological monitoring. Utilization pathways that convert CO2 into commercial products may open new markets and revenue streams.

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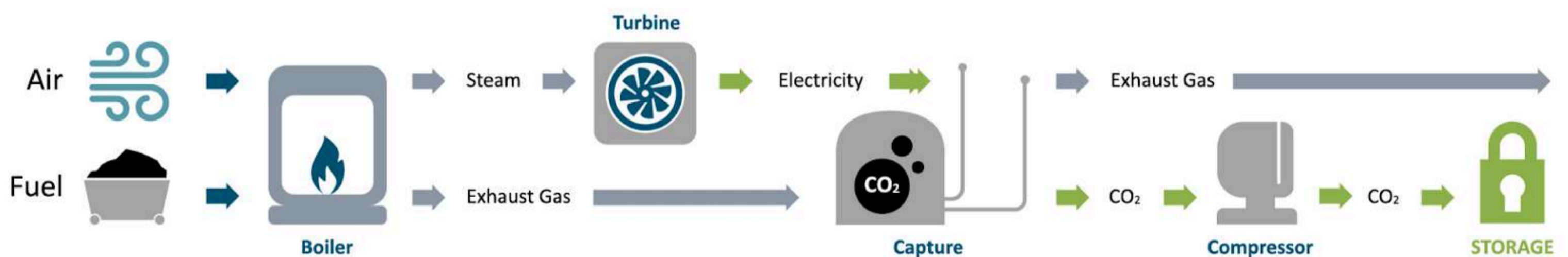


## Key Challenges

A major barrier to CCUS deployment is the high cost of capture systems, transport infrastructure, and storage site development. Capture energy requirements - known as the energy penalty - can reduce plant efficiency and increase operational costs, sometimes necessitating greater fuel consumption to sustain output. Many CCUS technologies remain at demonstration scales, and significant technical hurdles persist. These include material degradation in capture processes, challenges in pipeline transport of supercritical CO<sub>2</sub>, and the need for large-scale, corrosion-resistant infrastructure. Geological storage also poses risks related to containment integrity and leakage.

Public acceptance of carbon storage projects can be limited by concerns about CO<sub>2</sub> leakage, induced seismicity, and groundwater contamination. Inconsistent regulatory frameworks across regions further complicate project approvals and long-term liability arrangements for stored CO<sub>2</sub>. Although CCUS has been operational in select projects, real-world deployment remains limited relative to global emissions. Empirical analyses note that current efforts account for only a small fraction of emissions annually, highlighting a significant gap between theoretical potential and impact.

### Post-Combustion CO<sub>2</sub> Capture



## Discussion and Future Directions

Effective deployment of CCUS will require coordinated policy frameworks, supportive economic incentives, and continued research to lower costs and increase efficiency. Improvements in capture materials (e.g. advanced sorbents) and monitoring technologies could reduce technical barriers. Furthermore, integrating CCUS with renewable energy systems and hydrogen production pathways may enhance its role within broader decarbonization portfolios.



Carbon capture technologies offer important tools for reducing CO<sub>2</sub> emissions from sectors that are challenging to decarbonize. While benefits include greenhouse gas reduction, enhanced industrial decarbonization, and economic potential, significant challenges related to cost, energy use, infrastructure, and public acceptance must be addressed to achieve large-scale impact. CCUS should be pursued alongside aggressive emission reduction strategies, ensuring a multifaceted approach to climate mitigation.